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Seismic Emission in Geothermal Areas: Connection with Regional Seismicity

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ABSTRACT

Geothermal fields as active geophysical medium have a property of microseismic activity (seismic emission, SE). On Kamchatka (Russia) observation of small seismic signals is carried out in two locations – “Nachiki” (Nachikinsky hydrothermal field) and “Karymshina” (Paratunsky hydrothermal field). The investigations of seismic emission have been conducted on Kamchatka (Russia) since the end of the 1980s in the framework of the study of the fundamental problem of seismology connected with the possibility of monitoring overstressed medium conditions and preparation of strong earthquakes on the basis of geophysical field parameters.

The SE structure study gave an opportunity to distinguish components connected with Earth tides. It was found: (1) the response on tide impact is not stable in time; (2) the synchronization of the SE and tides is observed during some time (usually one-two months) before large (with magnitude $M \geq 6.0$) earthquakes; it is manifested as stabilization of phase shift between tidal component of the SE envelope and tides on a certain level. This specific feature of the SE response on tides is used for investigation of SE connection with large earthquakes. During the SE observations period (1992-2008) 22 earthquakes with $M \geq 6.0$ occurred on Kamchatka. The experimental data obtained in hydrothermal fields confirm the hypothesis about the correlation between values of stabilization level of the SE tide parameter ($\Delta\varphi$) with source characteristics of a preparing earthquake and its geographic position.

1. INTRODUCTION

The investigation of phenomena connected with crustal deformation caused by Earth tides is one of the fundamental problems of geophysics. The medium exposes their powerful deterministic periodical impact; as a result its parameters (conductivity, elasticity, viscosity, fluid-saturation, seismic and acoustic emission activity etc.) also change in a periodic manner. The variations of these parameters reflect the geophysical fields' dynamics in the upper crustal layers and consequently may contain information on the interior condition of the earth. Gravity impact of the Moon and Sun is considered as natural etalon of deforming forces having accurate mathematic description, ideally forecasting in time and space and acting in global scale (Melchior, 1966).

Seismic emission in the first tens of Hz frequency diapason with amplitudes about 10^{-9}-10^{-12} m is specified as high-frequency seismic noise (HFSN). The investigations of seismic noise on Kamchatka have been conducting for 20 years (Saltykov et al., 2007). During this time two stations of long-term observations have been organized: "Nachiki" (Nachikinsky hydrothermal field) in 1987 and "Karymshina" (Paratunsky hydrothermal field) in 1999 (Saltykov et al., 2006) (Figure 1). Besides, HFSN registration has been performed at the geophysical observatory on Erimo Peninsula (Hokkaido Island) since 1993 in the framework of scientific cooperation with Hokkaido University (Sapporo, Japan) (Saltykov et al., 2002). The last organized (2003) observation station is on Shikotan Island (Southern Kuriles).

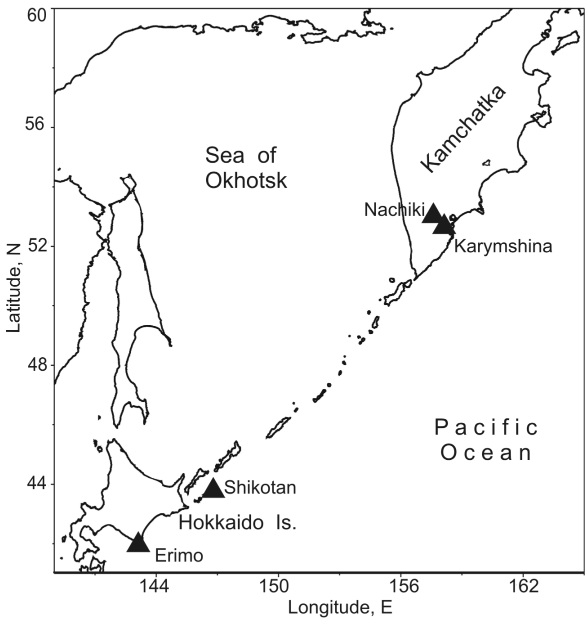

Figure 1. Scheme of location of recording points of high-frequency seismic noise. Triangles denote HFSN stations.

The effect of HFSN response on long-period deforming processes, earth tides in particular, was fixed in 1983 as scientific discovery; its authors are L.N. Rykunov, O.B. Khavroshkin, and V.V. Tsyplakov (Rykunov et al., 1984). It has principal significance because found modulation of micro-seismic emission by deforming processes has confirmed existence of endogenic components in seismic noise; it gave opportunity to consider them not as noise disturbance but as individual informative phenomenon. It gave foundations for the appearance of a new discipline in geophysics - micro-scale seismology (Rykunov, Smirnov, 1992). Besides, the discovery of this modulation is an additional argument supporting the active geophysical medium model (Nikolaev, 1991, Sadovsky, 2004); the last comprises both the idea of activity and high energy content of geological matter and idea of possible interaction of fields having different geophysical nature, their mutual influence including synchronization of processes.

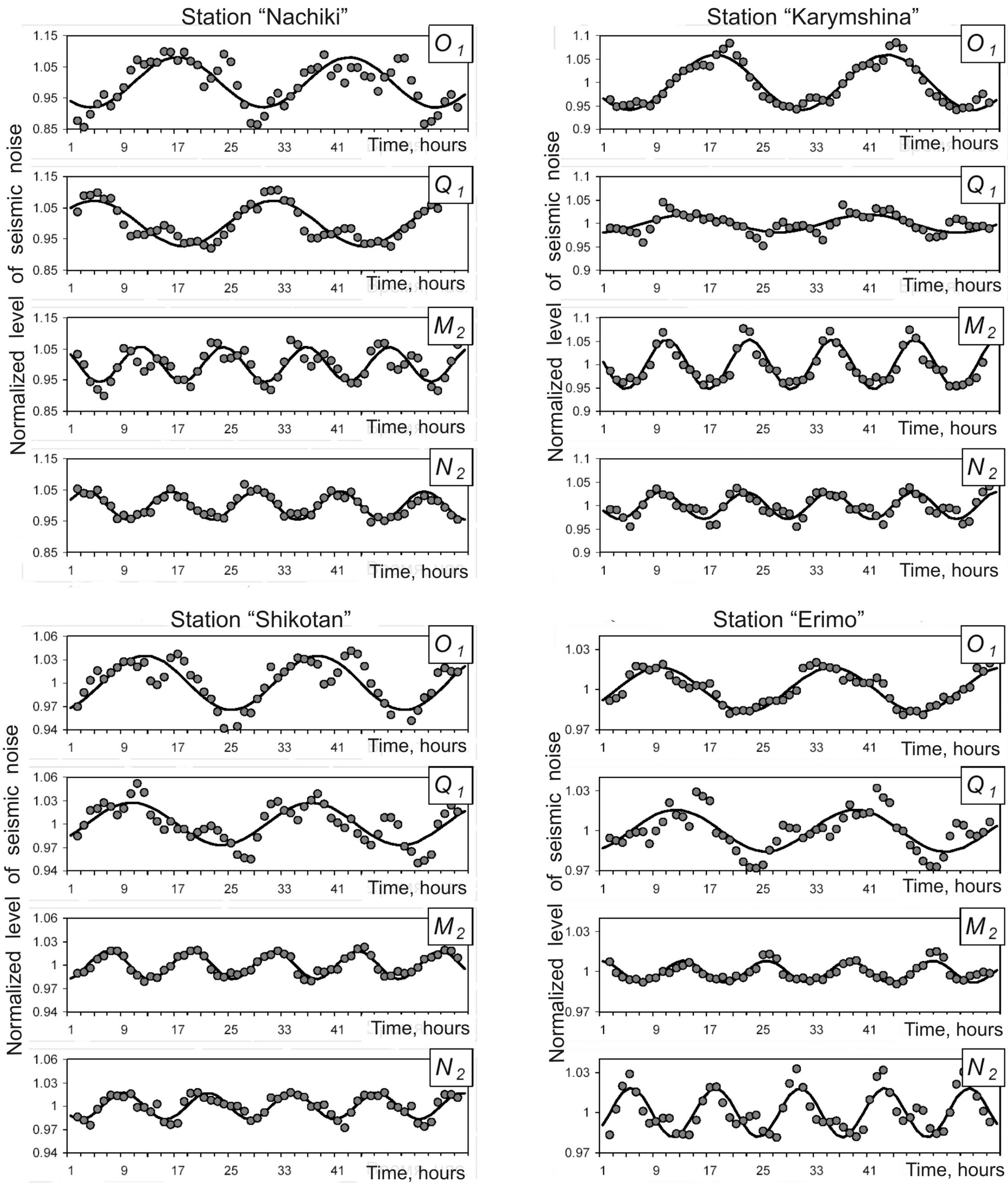

Figure 2. Variations in the HFSN envelope with the periods of the main tidal waves Q_1, O_1, M_2, N_2 based on the data of stations "Nachiki", "Karymshina", "Shikotan" and "Erimo" separated by coherent summing method.

The investigation of HFSN in seismically active regions such as Kamchatka, Kuriles and Japan represents special interest. These are the regions where it is possible to observe the HFSN variations caused by changes of stressed-deformed state of the medium, in particular during preparation and realization of strong earthquakes. And hydrothermal areas can be amplifiers of these effects.

Basing on long-term study of variations of HFSN envelope components (having periods of gravity potential main waves) (Figure 2) the prediction method was elaborated (Saltykov et al., 1998, 2007) which now is used for seismic hazard estimation (Gordeev et al., 2006). The original element of the method is usage of the Earth tides as an etalon impact having time-stable characteristics.

2. INSTRUMENTAL AND METHODICAL SPECIFICS OF THE HFSN REGISTRATION

To study the endogenic noise as a new seismologic object a new instrumental and methodical basis was created. One of its components is an organization of long-term regime observations and the other one is more quantitative metrology and first of all increasing of instruments sensibility. Standard seismometers don't provide sensitivity sufficient for registration of seismic noise in the 10-100 Hz frequency diapason. As a result the high-quality seismometers of resonance type with conversion ratio $(2\ldots7)\times10^6$ V/m and operational frequency diapason 15-40 Hz were created; in fact they represent the detectors of noise spectral components intensity (Rykunov, 1978).

The piezoceramic element is used as electromechanical converter. High quality ($Q \sim 100$) gives necessary sensibility and simultaneously provides frequency filtering of the signal.

Such seismometers are used at present time on the stations of HFSN registration "Nachiki" and "Karymshina" on Kamchatka, "Erimo" on the Hokkaido Island, "Shikotan" on the same-name island of the Smaller Kuril Chain (Saltykov et al., 2006b). As a rule the detectors are tuned on the operational frequency 30 Hz. The signal envelope is recording. The registration system is described in more detail in Saltykov et al., (2006b).

3. EFFECT OF HFSN SYNCHRONIZATION WITH TIDES BEFORE STRONG EARTHQUAKES

Phase shift $\Delta\varphi$ is considered as informative parameter in the HFSN study. This parameter is calculated from time mismatch between detected wave of tide gravity potential and the HFSN envelope component with corresponding period (Saltykov et al., 2006a). An important property of the HFSN response on tide impact was found: the effect is not stable in time. The areas of tide component presence alternate with areas of its absence; amplitude-phase relations between tide waves and the HFSN component vary. The HFSN response becomes ordered before strong earthquakes (Figure 3). The HFSN synchronization with external tide impact manifested in phase shift stabilization is considered as a prognostic indicator and represents a new earthquake precursor, which was not known before.

Wave O_1 was chosen as reference (pilot-) signal because on Kamchatka the HFSN envelope component with period of just this wave has maximum hindrance immunity (in conditions of exogenic noise disturbance with period T = 24.00 hour) and relatively high amplitude (Saltykov et al., 1997). The harmonic component with period T = 25.82 hours is extracted from the HFSN envelope in running time window having width 28 days with step 1 day using least-squares method. Its parameters are determined: amplitude and initial phase; the value of phase shift $\Delta\varphi$ may be obtained from the last.

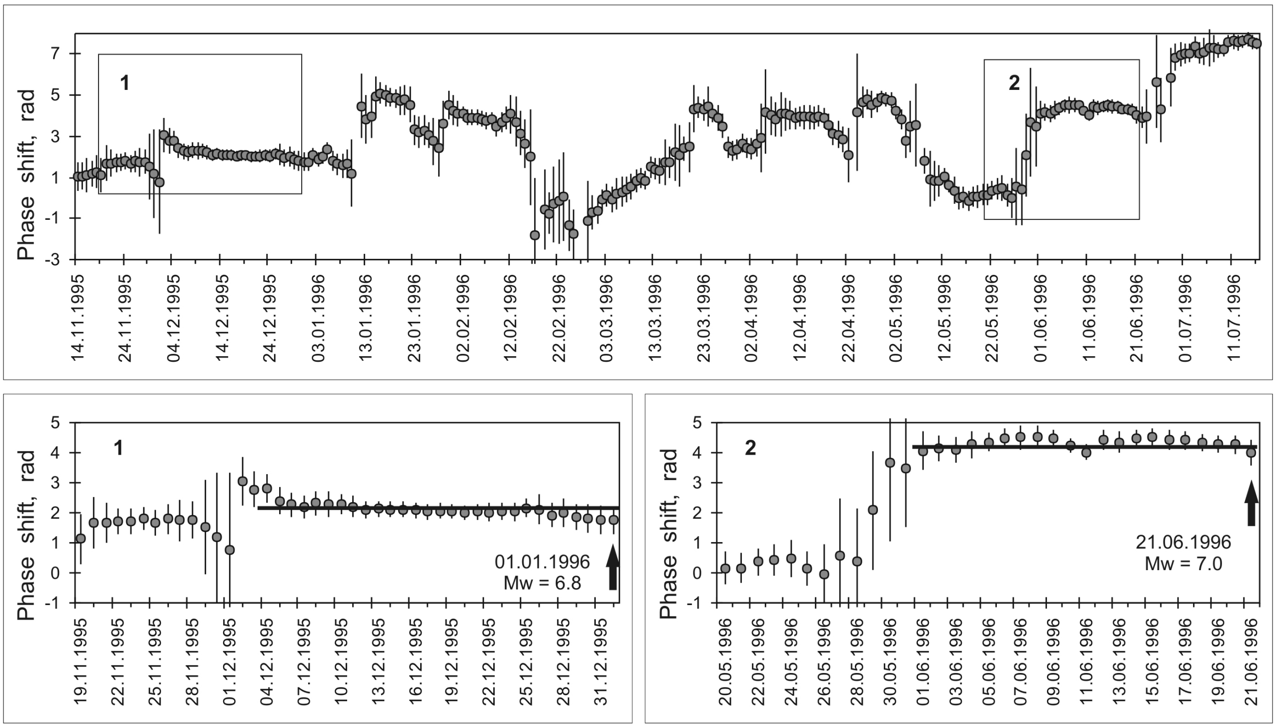

Figure 3. Timing code of parameter $\Delta\varphi$ and examples of synchronization of the tide component extracted from the HFSN with gravity potential wave O_1 before strong earthquakes on 01.01.1996, M = 6.6 and 21.06.1996, M = 7.0 (areas 1, 2)

4. MAIN RESULTS OF THE HFSN MONITORING ON KAMCHATKA

4.1. The statistics of Δφ stabilization before strong earthquakes discovery

The effect was found both in retrospect and in real-time regime for 28 earthquakes in 1992-2007 (Figure 4) in magnitude diapason from 5.0 to 7.8 for epicenter distances up to 400 km. 22 of these events had $M \geq 6.0$. There was only one earthquake from energy diapason $M \geq 6.0$ (08.03.1999, $M = 6.9$) before which the precursor was not found. The appearance of $\Delta\varphi$ precursors in 2001-2007 was simultaneously detected by Kamchatkan stations "Nachiki" and "Karymshina" before 7 earthquakes.

4.2. Determination of relationship "epicentral distance Δ - magnitude M"

Determination of relationship "epicentral distance Δ - magnitude *M*" was carried out for events of 1992-2006 accompanied by Δφ stabilization. Empirical relationship was constructed on base of precursors' determination results obtained in 1992-2206: $M \geq 4.0 + 0.008 \cdot \Delta$, where $\Delta < 400$ km ("Nachiki" station data).

4.3. The irregularity of phase shift distribution

The irregularity of Δφ distribution was revealed (Figure 4, incut). The $\Delta\varphi$ value for Karymsky crust earthquake on 01.01.1997 (hatched sector on Figure 4) lies apart from that of many other earthquakes of subduction type. The estimation of probability of less then 2 points appearance in hatched sector (if hypothesis of regular $\Delta\varphi$ distribution on the circle is accepted) gives value less than $3 \cdot 10^{-3}$. The irregularity of distribution assumes informative character of $\Delta\varphi$ stabilization level.

4.4. Grouping of the earthquakes by Δφ parameter in conformity with tectonics.

The analysis of $\Delta\varphi$ values correlation with earthquakes' epicenters location revealed spatial areas where seismic events were preceded by $\Delta\varphi$ stabilization on close values. Four groups were defined for shallow-focus subduction earthquakes from southern part of Kamchatka focal zone (Figure 5) (Group I: earthquakes № 12, 15, 21, 27; Group II: № 8, 17, 22, 23; Group III: № 3, 5, 6, 10, 24; Group IV: № 2, 4, 14, 26) and two groups for upper-mantle subduction events (Group V: № 18, 20; Group VI: № 16, 28). Earthquakes' numbers correspond to Figure. 4.

Grouping of shallow-focus earthquakes is well-correlated with recent disjunctive dislocations (Figure 5): earthquakes' groups relate to different blocks separated by faults according to (Seliverstov, 1998). It confirms that discovered effect has non-random character.

5. CONCLUSION

The results of retrospective precursor detection in other seismically active areas where HFSN observations are also conducted (Hokkaido and Shikotan islands) agree with the results obtained on Kamchatka, though have a number of peculiarities (Saltykov et al., 2002, Kugaenko et al., 2008). Consequently, the synchronization of the HFSN tide harmonic with corresponding wave of tide potential may be considered as a universal property of geophysical medium; it is connected with its stressed-deformed condition and manifesting, in particular, before strong regional earthquakes.

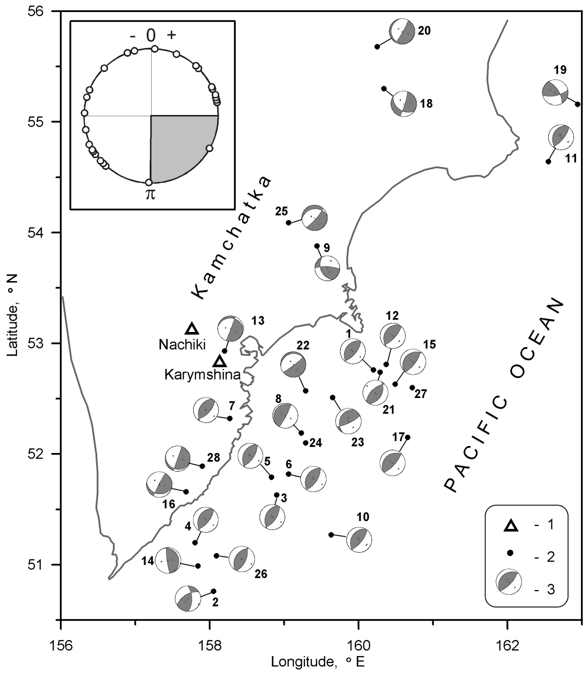

Figure 4. The 1992-2007 earthquakes before which the synchronization of the tide component extracted from the HFSN with gravity tidal potential wave O1 was detected. On the incut: values of Δφ stabilization level before presented earthquakes. 1 – HFSN stations, 2 – epicenters, 3 – source mechanisms.

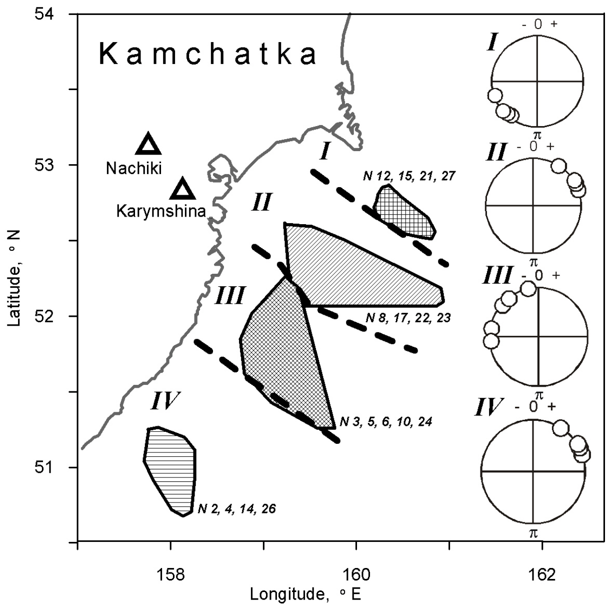

Figure 5. Areas including epicenters of earthquakes which are preceded by $\Delta\varphi$ stabilization on close values. Earthquakes numbers correspond to Figure 4. To correlate the areas with tectonics main faults located transversely to seismic focal zone (Seliverstov, 1998) are plotted on figure (dashed lines). On circular graphs $\Delta\varphi$ values for each group of earthquakes are shown.

On the other hand, the tidal effects in the HFSN on Kamchatka are brighter than in the other points. The cause of suspicion is the location of seismic station in hydrothermal areas. Probably, this fact must be taken into account when choosing the observation points.

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